EXTENSION OF STEAM-ELECTRIC PLANT AT METROPOLIS, ILLINOIS

BY

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THESIS

FOR

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IN

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COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

EDWARD WEBB BROWN

ENTITLED EXTENSION OF STEAM-ELECTRIC PLANT AT METROPOLIS, ILLINOIS

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Electrical Engineering

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EXTENSION OF THE STEAM-ELECTRIC PLANT AT METROPOLIS.

The power plant at Metropolis, Illinois is owned and operated by the city, in conjunction with the water works. It is very poorly equipped, and gives very poor service. The electrical equipment consists of 1-100 K.W., 133 cycle, 1100 volt generator and 1-70 lamp Wood arc machine. The generator is of poor design, getting excessively hot at three fourths full load. It is of the inductor type. The heating is probably due to excessive iron losses. There are no reserve units, hence a breakdown means shutting down the plant.

The feeder system is so designed, that a short circuit on any feeder will cause half the system to be thrown out, for power is carried out on two main circuits, each of which divides at some distance from the station. The feeders are poorly designed, and the regulation in some parts of the town is very poor. At the time of peak load, the lights in the business district become very dim, but will brighten as load lessens. At the same time, the lights in the resident districts will burn brightly during peak load, but will get dimmer as load falls off. This is due to fact that the feeder leading to business district is overloaded, and there is a large line drop. The voltage at the station is raised during peak load to overcome this, hence feeders to resident districts, which do not have very large line drop, will have higher voltage, than they will at a time when voltage is lower at station.

The electrical machines are driven by 1-250 H.P. Corliss

Engine, running at 85 R.P.M., using steam at 100 pounds gage. This engine is belted to line shaft, which is belted to machines. A friction clutch is inserted in the shaft, that the arc machine may be cut off at any desired time.

The steam generating plant consists of 2-60 H.P., and 1-150 H.P. boilers. In addition to furnishing steam for engine, the boilers must furnish steam for pumping plant. Since the pumping is done during light load, no extra boiler capacity is allowed for this.

The pumping plant consists of two steam driven air compressors, and two pressure pumps. The water is forced from 250 foot wells by means of an air lift, and flows into an underground reservoir. From there it is pumped directly into mains. One pump is kept in reserve.

In extending this plant, I have changed the frequency from 133 to 60 cycle. Motors of 133 cycle are difficult to obtain, and large ones are not manufactured. Since 60 cycle is standard, and suitable for both lighting and power, I have chosen this frequency. A load curve of plant taken last December is shown on sheets #16 and #17. By making a canvass of small shops, manufacturers and residences, I have constructed a load curve, which could be realized with proper installment. I found that many residences were not electric lighted, due to poor service and to the fact that the plant will not take on any more load with their present equipment. Many stores are installing gas lights on account of poor service. Instead of series arc lights for street lighting as now used, I have chosen 60 watt series Tungstens, three being placed in each block. This installation requires more power than

the

present system of street lighting, but gives a much better distribution. A day load of about 80 K.W. could be obtained. With this data I have constructed the load curve for twenty-four hours, shown on sheet, for the month of December. In summer the peak load will come later, and will not be as great nor last as long, for many stores close at seven o'clock, and factories will need no light at all. On moonlight nights, the night load will be considerably less,as street lamps are not burned on these nights.

In selecting machines to fit load curve, I have chosen 3-100 K.W.,1100 V., three phase machines. One machine is sufficient to carry day load, and night load between the hours of ten-thirty and four-thirty. At peak load, two machines will carry the load if necessary each being about ten per cent overloaded for a short period of time. Thus one unit is in reserve in case of breakdown. The plant is located in such a place that power is transmitted over a semicircular area, the greatest distance of transmission being a little more than one mile. The power sent out to edge of town is small, hence 1100 volts will be sufficient.

As the machines are to run in parallel, I have chosen for the additional prime mover, 1-150 H.P. Corliss engine, running at same speed as engine already installed. This engine will be sufficient to carry day load, and the night load between hours of ten-thirty and four-thirty. The steam pressure used is 100 pounds gage. In case of breakdown of small engine, by increasing steam pressure, the 250 H.P. engine could carry peak load.

The engines are belted to line shaft, which runs at 300 R. P.M. This shaft is cut into three sections by means of friction clutches. With this arrangement, the shaft can be cut into three pieces, each belted to a generator. The shafts may be coupled together and driven by both engines, running the three alternators in parallel. It may be run in two sections, the large engine driving two generators, and the small engine driving one generator, or each engine may drive a generator, the middle generator being idle. In all cases the generators may be run in parallel.

The exciters are direct connected to the alternators, hence requiring less floor space and less belting. One lead from exciter field, and both leads to generator field are brought to switch board.

The switch board is located between the two engines in such a position that it can be seen from either engine throttle. It is made up of eight panels, three generator and five feeder panels. Three feeders are placed on each feeder panel, two feeder panels are for lighting and power and the other three for street lighting. An air break three pole switch is used for connecting generators to bus bars. A three pole circuit breaker is placed between alternator and bus bar. An ammeter is placed in each phase, for convenience in keeping phases balanced. One voltmeter is placed on each panel, with plug connections for placing it across either phase. The voltmeter is placed across a step down potential transformer. Lamps are used for synchronizing. The lamps are so placed, that if the plug on machine running, and plug on machine started be inserted, the lamps of the two machines will be in series across the potential transformers of the two machines. When transformers are used, the machines must be synchronized during light period, hence it is easier to tell exact instant of throwing switch. The same potential transformer is used for both lamp and voltmeter. Two Rheostats are mounted on each generator panel, one for generator field and one for exciter field. A two pole switch is placed between exciter and exciter field. An ammeter is placed in each generator field to measure exciting current. Three two pole double throw switches are placed on each feeder panel. The feeder is connected to middle terminals , and outer terminals are connected to different phases. By means of these double throw switches, a single feeder may be supplied from either of two phases, thus making it possible to keep phases balanced. A single pole circuit breaker is placed in each feeder to light and power, and a fuse in each feeder to street series lamps. An ammeter is placed in each feeder, for the purpose of assisting in balancing up load on phases.

Lightning arresters are to be installed in each feeder circuit. These will be placed just outside of generating room, where feeders are brought out.

Six feeder circuits carry current for lights and power. Circuit #1 runs west along First street to Broadway, then north to edge of city. It furnishes lights for residences and factories in western and south western part of city. A small amount of power is carried by this feeder to small factories located on river front. Circuit #2 runs east on First street and furnishes light and power to factories. Most of these factories are large and are steam driven, hence this circuit transmits very little current for power. The lighting load will be heavy on this feeder in winter, but light in summer, as the factories close at five-thirty. During certain seasons of the year, some of the factories run twelve and one half hours a day. It would not be advisable to attempt to furnish residence lights from this circuit, as it will be very heavily loaded at time of peak load in winter. Circuit #3 runs north to Third street, west to Ferry street, north to Sixth street and west to Market street. This feeder carries current for lighting business buildings, which are located on Third street between Metropolis and Ferry streets, on Ferry street between Front and Fifth streets, and on Market street between Sixth and Seventh streets. Circuit #4 runs north on Catherine street and furnishes lights to residences in part of city north of Twelfth street. Circuit #5 runs north on Catherine street, carrying current to all residences located in area bounded by Market, Ophia, Twelfth and Front streets excluding business districts. Circuit #6 runs north to Fifth street, thence east, carrying current to lights in residences east of Ophia street, and to business buildings on Scott street. I have arranged the feeders, so that no feeder shall have a maximum load of more than 45 K.W. Feeders #2 and #3 will carry maximum load during winter months, at time of peak load, but during summer months, the load will be comparatively light at this time. #2 will be heavily loaded on

Saturday nights, and on fifth and twentieth of each month, which nights are pay nights, for stores stay open till a late hour.

The street lamps are series tungsten, and take 5.5 amperes with 11.3 volts drop across each lamp. Ninety-five of these lamps may be placed in series. I have arranged these circuits, so that each one will have practically same length of line.

I have chosen 1-150 H.P. boiler, of the horizontal fire tube type, for addition to steam generating plant. (See Calculations).

No additional feed water pumps are needed. The present equipment consists of two pumps, either of which is capable of pumping water for the four boilers.

A vertical feed water heater was installed about a year ago, and is of sufficient capacity to take care of exhaust steam from both engines. The exhaust pipe is placed under floor running to point near heater, where it is brought up and enters top of heater. A drain is placed in the lowest point of exhaust pipe. The feed water enters heater from main under pressure. It flows by gravity into pumps, and is forced into pipe, which is connected through valves to all the boilers. Either pump may be used, thus allowing for breakdown.

The steam piping from boiler room consists of a single header, six inches in diameter up to first engine, and four inches in diameter to second engine. These sizes are somewhat larger than sizes derived by means of formula in Koester. (See Calculations). Valves are placed in pipes just beyond point where branch for first engine is taken off, and between each boiler and header. The water pumping plant may be cut off by valves near header.

The chimney is six feet inside diameter, and ninety feet high, being of sufficient capacity according to tables in Koester.

The coal is brought in cars up to bin, where it must be shoveled from car to bin. It is then shoveled from bins to furnace. The space between boiler front and coal bin is nineteen feet, being sufficient to permit cleaning of boiler tubes. An ash car is brought in front of boilers, and ashes shoveled into it. They are then carted outside and dumped.

Calculations:-

I have assumed 25 pounds per H.P. hour as steam consumption. The 150 H.P. engine requires 150 times 25 equals 3750 pounds steam per hour. One boiler H.P. has an equivalent evaporation of 34 $\frac{1}{2}$ pounds per H.P. hour, and requires $34\frac{1}{2} \times 966 = 33300$ B.T.U. One pound of steam at 100 pounds pressure contains 1185 B.T.U. above 32° F. Feed water temperature is 175° F. Hence $1185-(175-32) = 1042$ B.T.U. must be furnished to each pound of water. One boiler H.P. will evaporate $33300/1042 = 31.9$ pounds water. $3750/31.9 = 117.5$ H.P. = capacity of boiler needed. I have chosen 1-150 H.P. horizontal fire tube boiler, which will be sufficient to carry engine at 28 per cent overload without overloading boiler.

Calculations for size of pipe.

Engine requires 25 pounds steam per I.H.P. hour.

Assuming 80 per cent efficiency for engines.

Steam required per hour equals$(400 \times 25)/.8 = 12500$ pounds.

Steam pressure = 100 pounds gage.

Drop in pressure = three per cent = three pounds.

Actual length of pipe = 66 feet.

Assuming six inch pipe, 20 feet must be allowed for bend, and 38.4 feet for Ts.

Hence equivalent length of pipe = 124.4 feet.

Weight of steam in pounds per cubic foot = .263 = D.

Assuming velocity of 4000 feet per minute

$$P = 1/900000 \times Q^2L/d^5D.$$

$$3 = 1/9000000 \times ((12500)^2 \times 124.4)/d^5 \times .263$$

$$d^5 = 2745$$

$$\log d = 1/5 \log 2745$$

$$d = 4.9 \text{ inches}$$

Six inch pipe was chosen up to first engine, and four inch pipe from there to second engine.

Calculations for amount of coal used.

Assuming steam consumption of 25 pounds per H.P. hour

The load factor obtained from load curve (average) is .268.

Efficiency of engine equals 80 per cent and efficiency of generator equals 90 per cent.

Amount of steam required per hour (maximum) is

$$(25 \times 300 \times 1.34)/(.90 \times .80\ ) = 14000.$$

At 100 pounds steam pressure, feed water temperature at

175°, one pound of steam requires 1042 B.T.U. furnished by boiler.

With boiler efficiency of 70 per cent, the coal must furnish (1042)/.7 = 1490 B.T.U. per pound steam.

Using southern Illinois coal having heat value of 12000 B.T.U. per pound, (14000 x 1490)/12000 = 1740 pounds of coal per hour will be required at full speed.

Average coal consumption per hour equals

.268 x 1740 = 466 pounds.

Cost of coal is $1.25 per ton in cars at plant.

Cost of coal per year is (365 x 24 x 466)/ 2000 x $1.25 = $2560.

Calculations for size of feeders, assuming three per cent drop.

Circuit #1.

Current Amp.	Distance Feet	Wire needed Feet	Equiv. Current per 1000 ft. wire
21.8	1200	2400	52.5
17.25	960	1920	33.2
12.70	880	1760	22.4
8.20	720	1440	11.8
5.50	1280	2560	14.1
2.70	1680	3360	9.3

6080 feet number two wire weighs 1216 pounds.

7360 feet number six wire weighs 590 pounds.

Weight of wire used 1806 pounds.

Circuit #2.

36.4	1360	2720	99.0

36.4	880	1760	56.0
22.7	960	1920	43.2
18.2	960	1920	35.0
13.6	1040	2080	28.4

10400 feet number one wire weighs 2620 pounds.

Weight of wire used 2620 pounds.

Circuit #3.

40.9	2240	4480	186
22.7	800	1600	36.3
13.6	960	1920	26.0

6080 feet of number one wire weighs 1540 pounds.

1920 feet of number four wire weighs 242 pounds.

Weight of wire used 1782 pounds.

Circuit #4.

13.6	5280	10560	144
10.9	720	1440	15.7
5.45	800	1600	8.8
2.75	1280	2560	7.1

10560 feet number two wire weighs 2110 pounds.

5600 feet of number four wire weighs 705 pounds.

Weight of wire used 2815 pounds.

Circuit #5.

26.4	880	1760	45.4
21.8	480	969	21.0
19.1	880	1760	33.6
14.5	880	1760	25.6
7.3	880	1760	12.9

4.55	880	1760	8
2.73	1920	3840	10.5

6240 feet number three wire weighs 990 pounds.

7360 feet number four wire weighs 925 pounds.

Weight of wire used 1915 pounds.

Circuit #6.

22.7	2320	4640	106
20.0	400	800	16
14.6	400	800	11.8
11.8	1040	2080	24.6
9.1	800	1600	14.5
4.6	400	800	3.7

6240 feet number three weighs 1250 pounds.

4480 feet number four weighs 565 pounds.

Weight of wire used 1815 pounds.

Series Circuits.

Length of wire needed in one circuit = 22000 feet.

Number eight wire is used weighing 50 pounds per 1000 feet.

Nine circuits are used.

Weight of wire used = 22 x 9 x 50 = 9900 pounds.

Table of Costs.

Equipment.

Switch board and instruments	$1850
Erecting switch board	30
Engine, including setting and labor	2650
Generators, including setting	4200
Boiler, including setting, piping and erecting	1775

Shafting, belting,etc.	$ 990
Transformers	1865
Wire (22700 pounds @ $.15)	3405
Series Tungsten lamps	900
Brackets for lamps	2430
Poles (400 new) including setting	350
Cross arms, braces, pins,etc.	750
Insulators	240
Value of engine and boilers already installed	5000
Total	$26435

Buildings and Grounds.

Approximate value of buildings and grounds	$7000
Approximate cost of extending building	3700
Total	$10700

Operation costs per annum.

Coal	$2650
Int. and Dep. (bldg. and gr.) at 8 %	855
Int. and Dep. (equip.) at 14 %	3560
Labor (six men)	4400
Oil,waste, etc.	400
Total	$11865

Output in K.W.H. per year = 300 x .268 x 24 x 365 = 705000

Cost per K.W.H. equals 11865/705000 = $.0131

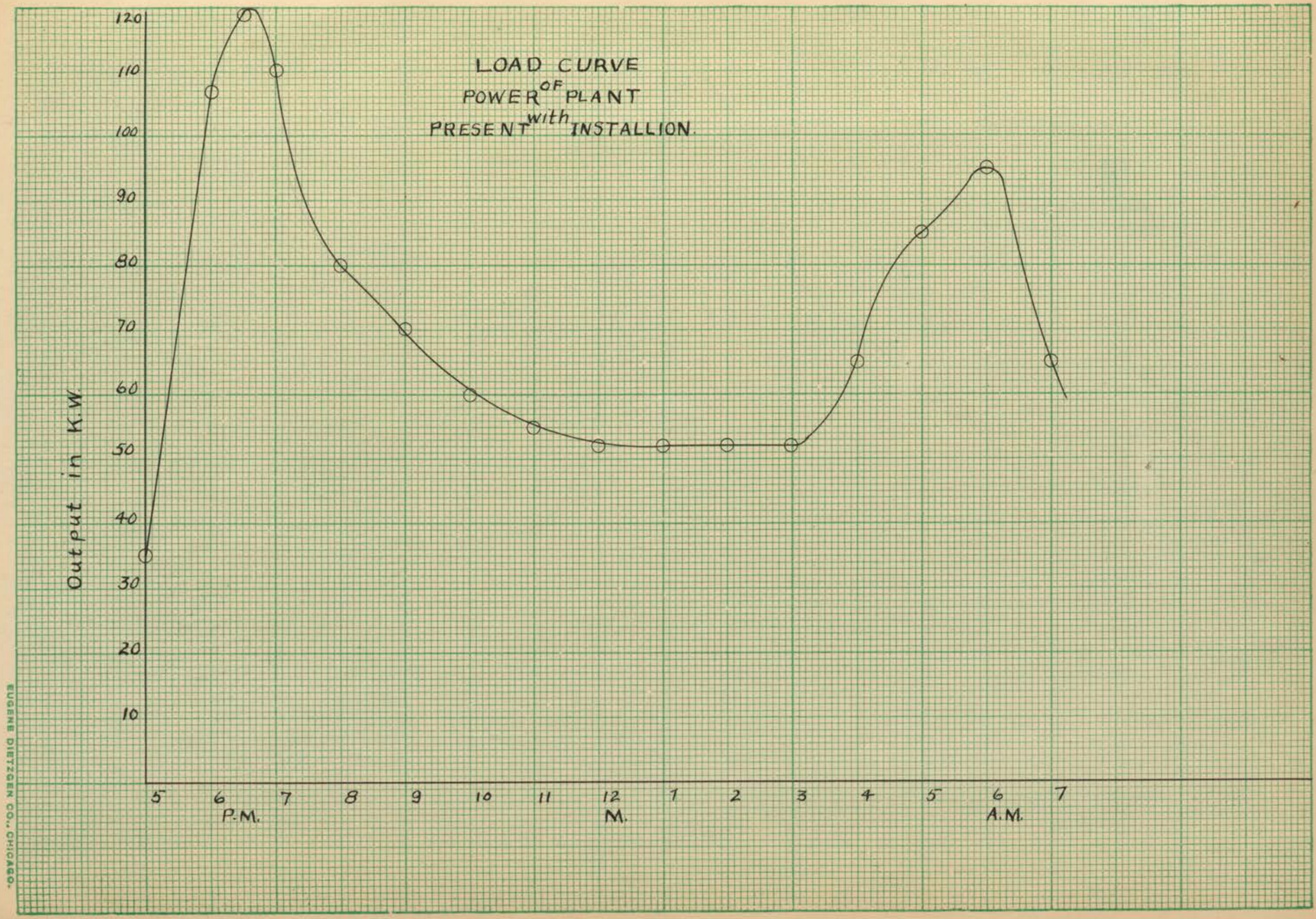
Assuming $.05 as the average rate of selling,

.05 - .0131 = $.0369 = amt. to be realized per K.W.H.

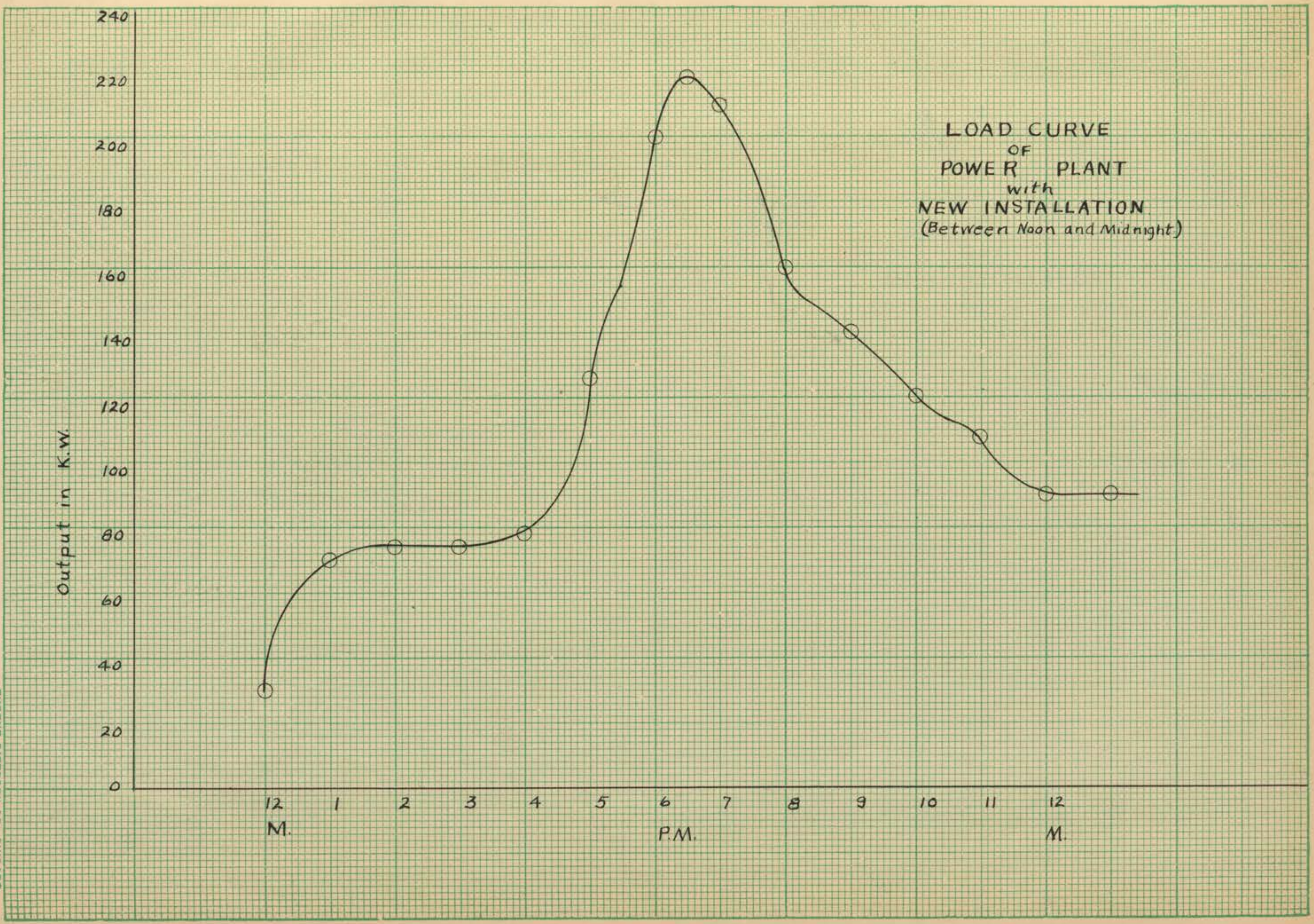
157500 K.W.H. per year is used by street lamps.

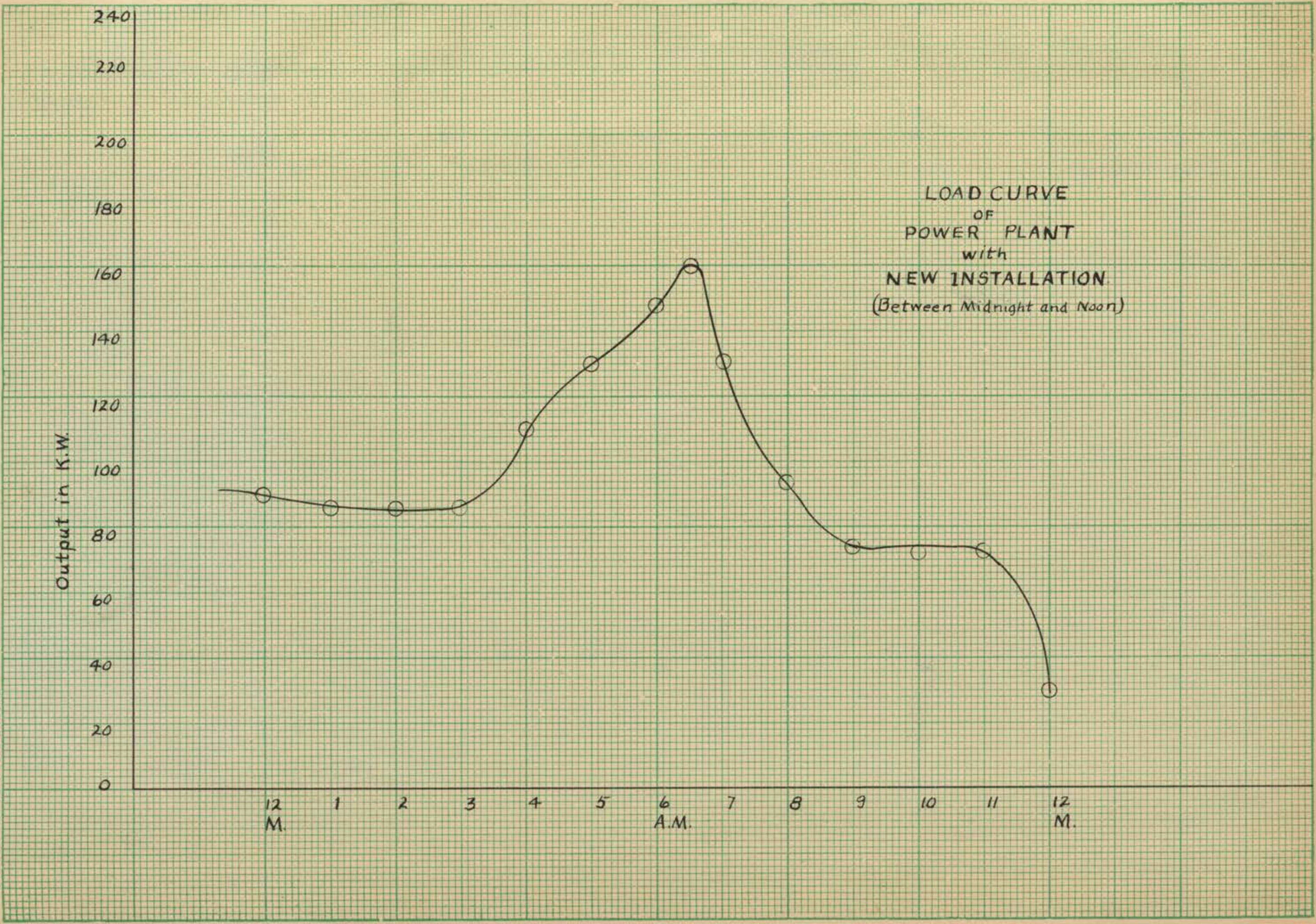
705000 - 157500 = 547500 K.W.H. disposed of to customers.

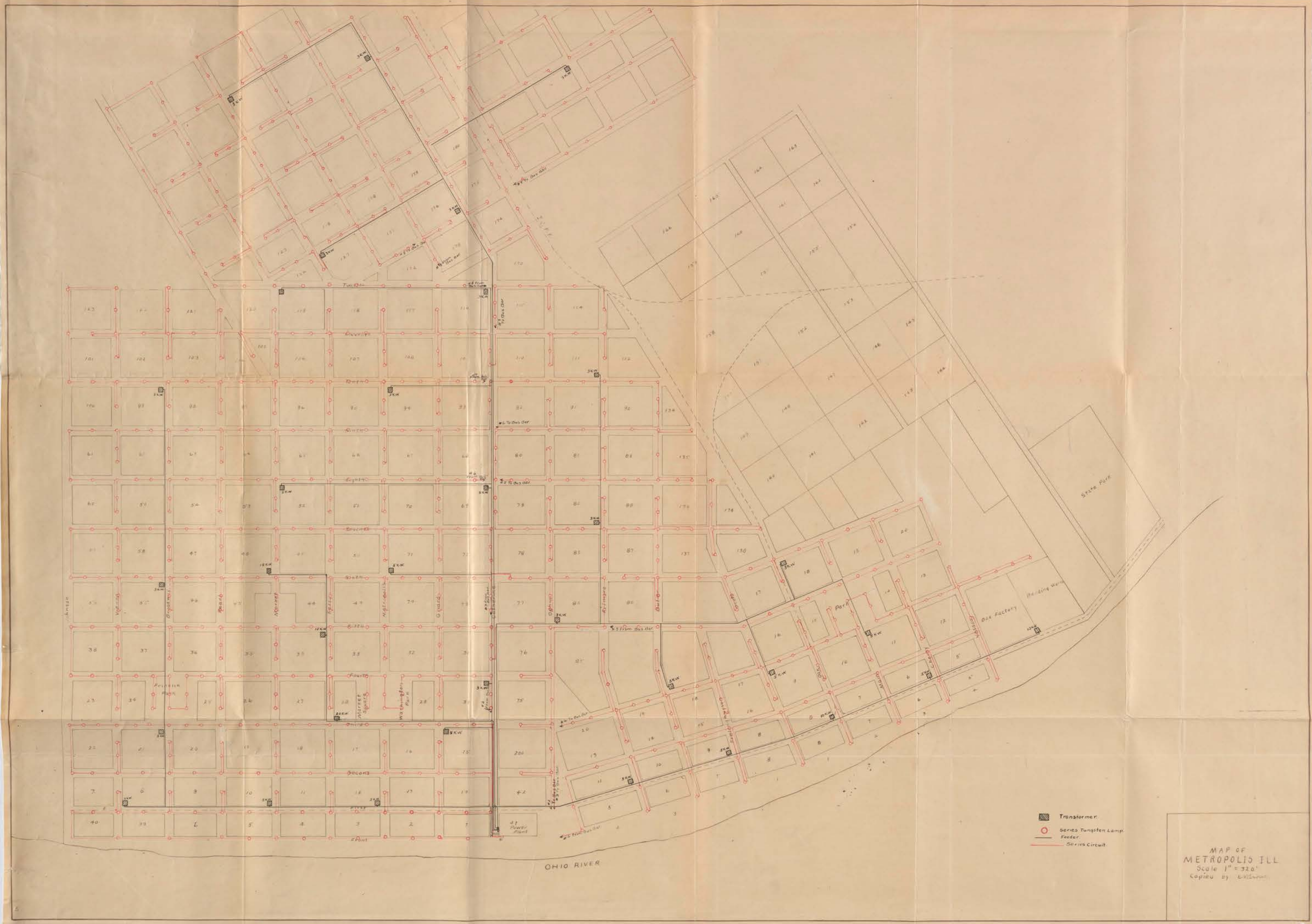
547500 x $.0369 = $20200 to be realized each year from investment.



LOAD CURVE
POWER OF PLANT
PRESENT with INSTALLION.
Output in K.W.
120
110
100
90
80
70
60
50
40
30
20
10
5
6
7
8
9
10
11
12
1
2
3
4
5
6
7
P.M.
M.
A.M.
EUGENE DIETZGEN CO., CHICAGO.


LOAD CURVE
OF
POWER PLANT
with
NEW INSTALLATION
(Between Noon and Midnight)
Output in K.W.
240
220
200
180
160
140
120
100
80
60
40
20
0
12 1 2 3 4 5 6 7 8 9 10 11 12
M.
P.M.
M.


LOAD CURVE
OF
POWER PLANT
with
NEW INSTALLATION
(Between Midnight and Noon)
Output in K.W.
240
220
200
180
160
140
120
100
80
60
40
20
0
12 M.
1
2
3
4
5
6 A.M.
7
8
9
10
11
12 M.



Transformer
Series Tungsten Lamp
Feeder
Series Circuit
OHIO RIVER
Power Plant
State Park
Box Factory
MAP OF
METROPOLIS ILL
Scale 1" = 320'
Copied by

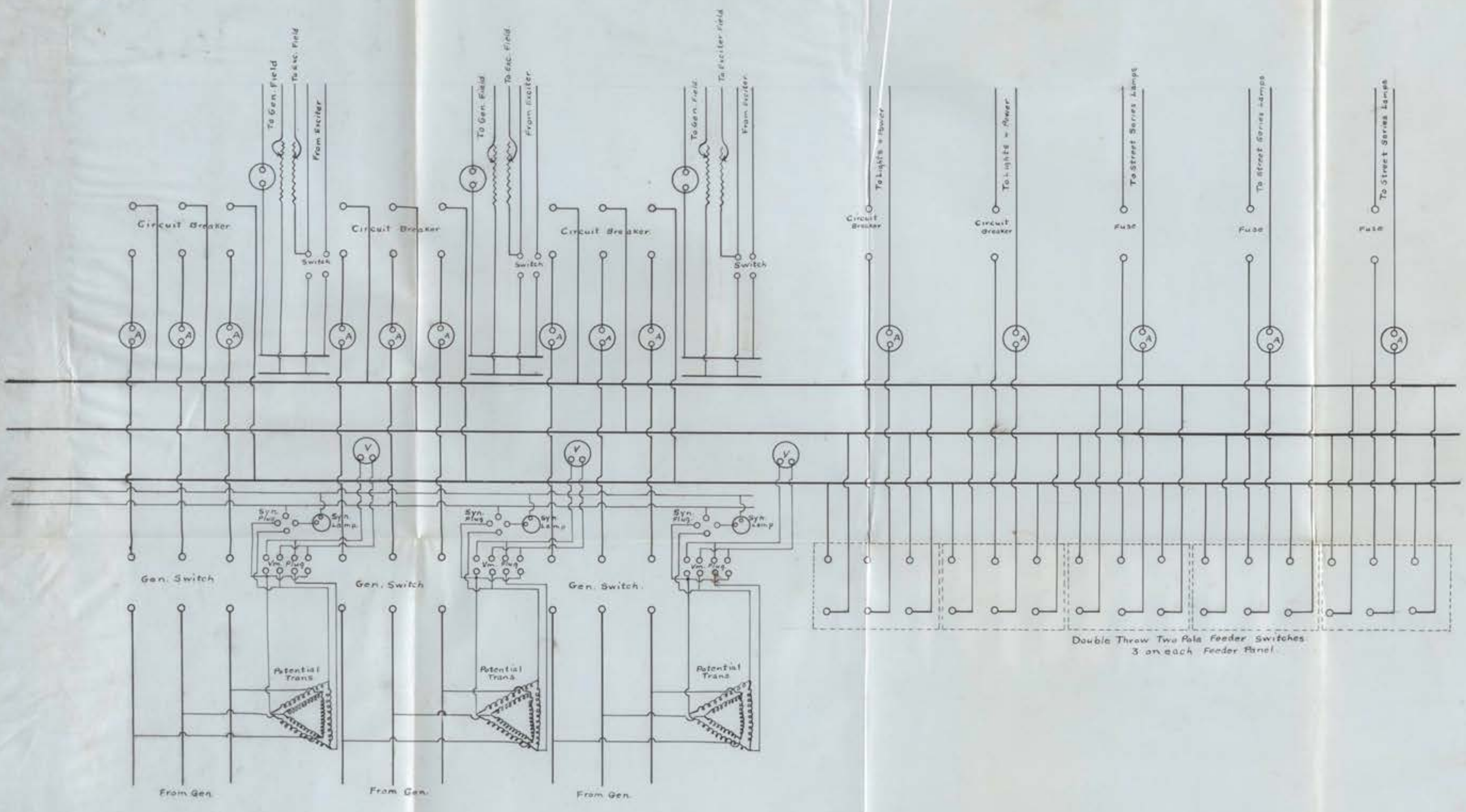
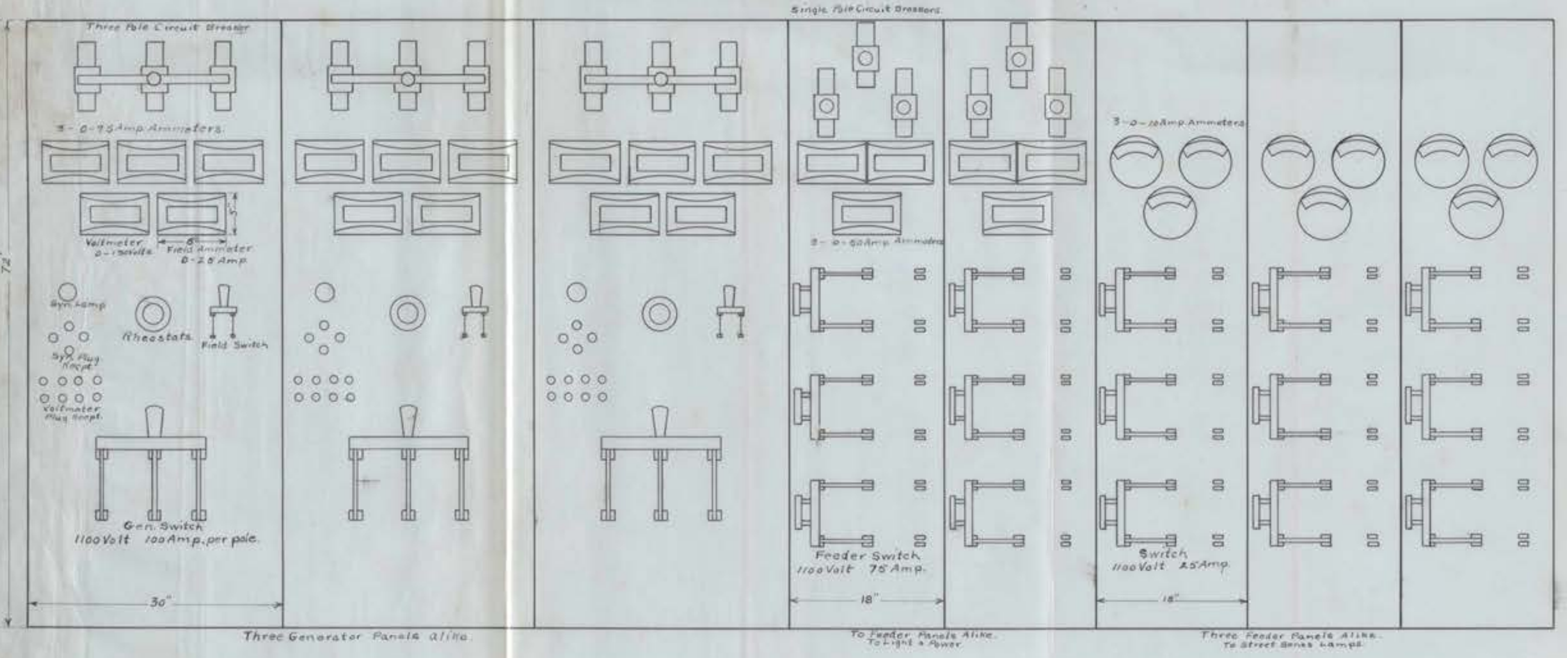
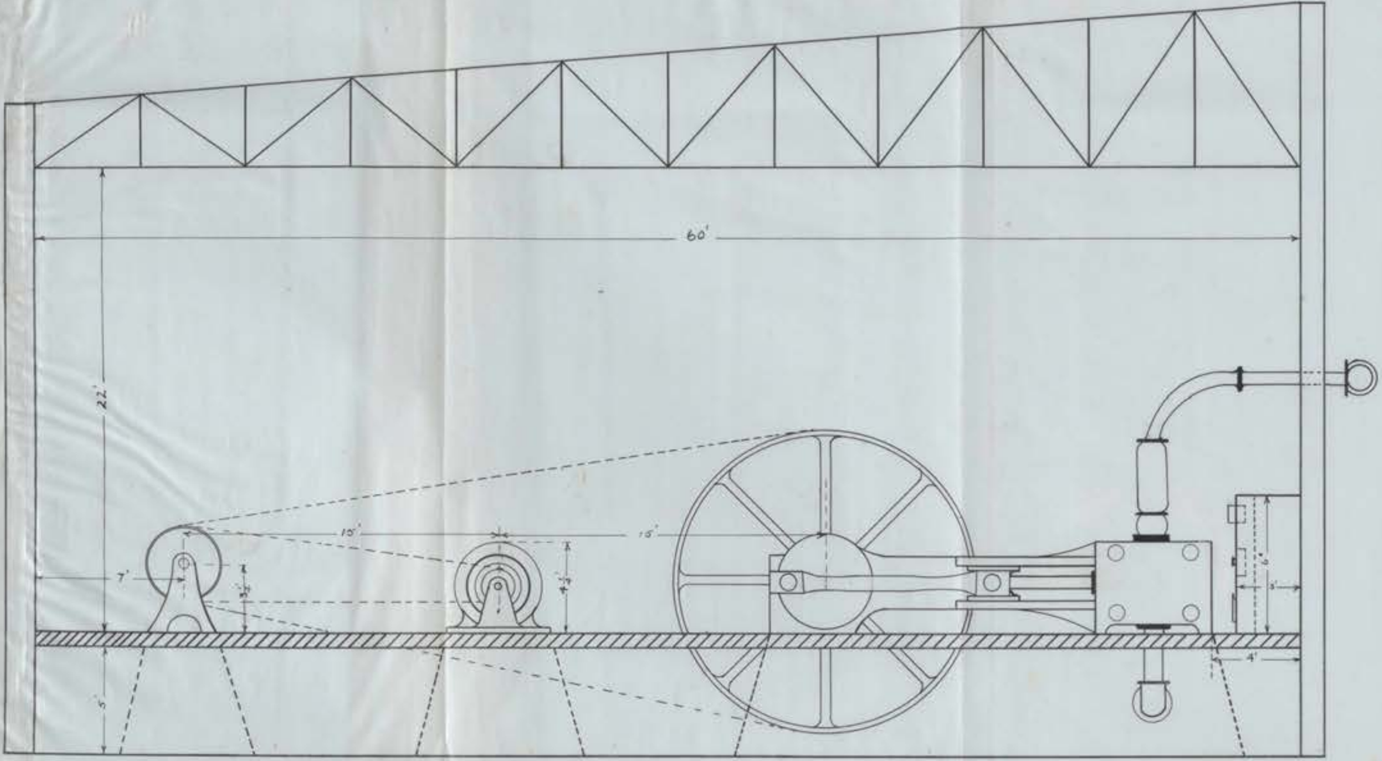


DIAGRAM
OF
SWITCH BOARD CONNECTIONS
FOR
POWER PLANT AT METROPOLIS ILL

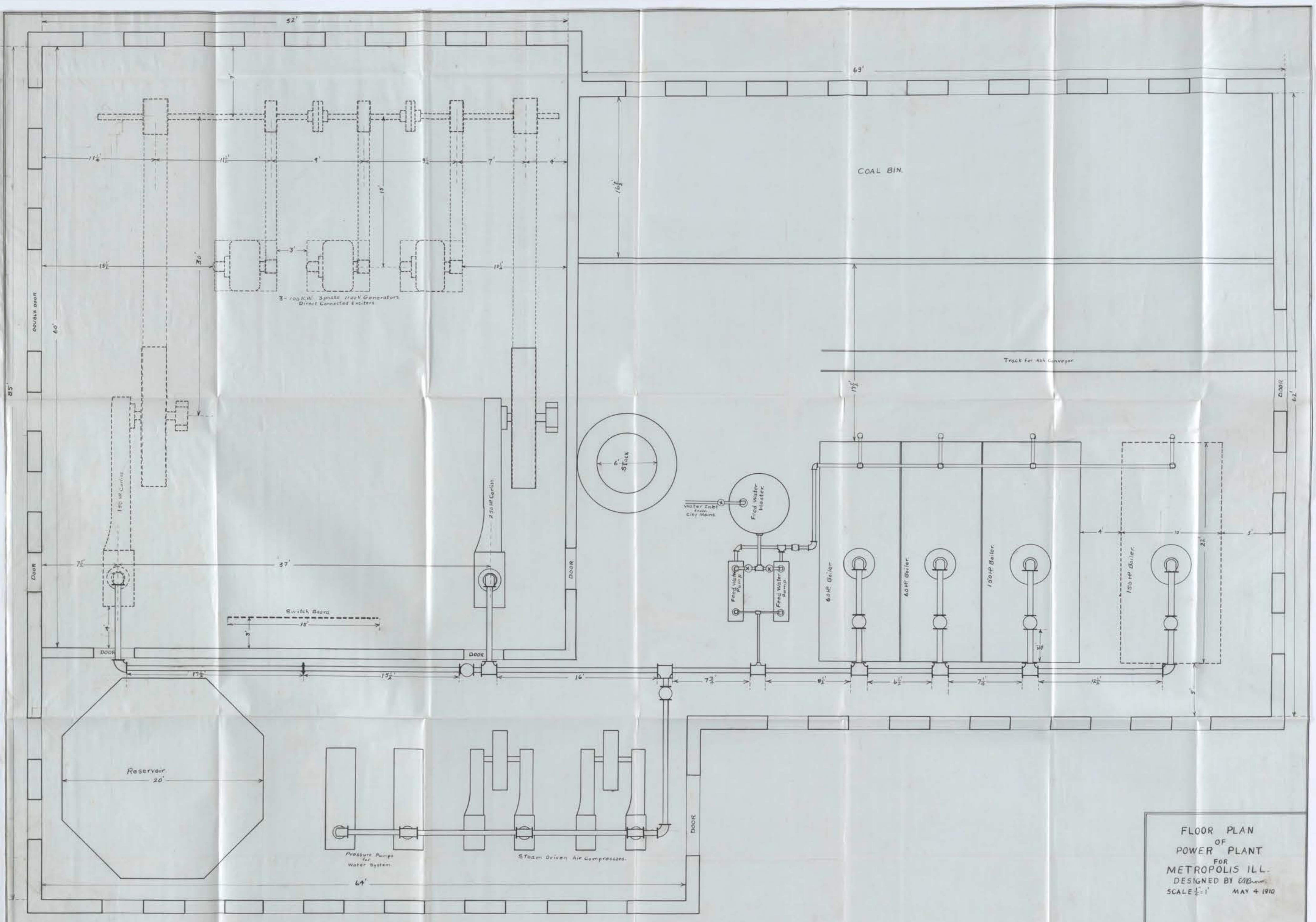
Designed by C.H.Brewer May 4 1910



SWITCH BOARD
FOR
POWER PLANT AT METROPOLIS ILL
DESIGNED BY
E. M. Brown
SCALE $\frac{1}{10}" = 1"$ MAY 4 1910



ELEVATION OF
POWER PLANT AT
METROPOLIS ILL.
DESIGNED BY
E W Browning MAY 4, 1910
SCALE $\frac{1}{4}$" = 1'



COAL BIN.
Track for Ash Conveyor.
3-100 K.W. 3phase 1100V Generators
Direct Connected Exciters
150 HP Corliss
250 HP Corliss
6' Stack
Water Inlet from City Mains
Feed Water Heater
Feed Water Pump
Feed Water Pump
60 HP Boiler
60 HP Boiler
150 HP Boiler
150 HP Boiler
Switch Board
Reservoir
Pressure Pumps for Water System.
Steam Driven Air Compressors.
DOUBLE DOOR
DOOR
FLOOR PLAN
OF
POWER PLANT
FOR
METROPOLIS ILL.
DESIGNED BY
SCALE $\frac{1}{4}$" = 1'
MAY 4 1910